NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3250

AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF WHEEL PREROTATION ON LANDING-GEAR DRAG LOADS

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Washington
October 1954

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SUMMARY

The effect of prerotation on the wheel spin-up drag loads on a small landing gear during landings has been investigated by means of tests in the Langley impact basin. A series of simulated landings with various amounts of prerotation was made with a dropping weight of 2,500 pounds and a forward speed of 85 fps at a strut angle of 15°. The results were compared with data from previous tests made with various forward speeds and no prerotation. The effect of prerotation on the maximum drag load was the same as the effect of reducing the horizontal velocity. At low horizontal velocities any amount of prerotation reduced the drag load. The reduction became greater as the vertical velocity was increased. Reductions in drag load resulting from prerotation were accompanied by reductions in vertical load. At high forward speeds somewhat beyond the range where prerotation was tested, however, consideration of existing data indicated that large amounts of prerotation would have to be used in order to assure a reduction in drag load. In this higher speed region, insufficient prerotation could actually increase the drag load. The wheel spin-up process appeared to be a small factor in tire wear and prerotation therefore should not materially increase tire life.

INTRODUCTION

The prerotation of airplane wheels has been the subject of some investigations in the past. These investigations were, for the most part, concerned with developing a method of prerotating the wheels, rather than with obtaining actual measurements of the supposed benefits of prerotation, that is, reduction of the structural loads during landing and reduction in tire wear. In order to obtain quantitative data regarding the effect of prerotation on wheel spin-up drag loads, a series of tests was conducted in the Langley impact basin with a main landing gear designed for a small trainer airplane weighing about 5,000 pounds. The tests were made with prerotation varying from 0 to 115 percent at a forward speed of approximately 85 fps.

This paper presents the results of these tests, a comparison with data obtained in the investigation of wheel spin-up drag loads without prerotation presented in reference 1, and a discussion of the effects of the various parameters.

EQUIPMENT AND TEST PROCEDURE

In order to obtain the measurements of the applied ground loads in the study of prerotation, tests were conducted in the Langley impact basin (ref. 2). The impact-basin carriage provides means for controlling the descent of the test specimen with a predetermined vertical velocity and simulated wing lift while the carriage travels horizontally at a predetermined velocity. The adaptation of this equipment for the drop testing of landing gears is described in reference 3. In order to use this equipment for testing landing gears with forward speed, a temporary concrete runway was installed in the impact basin (fig. 1). The method used in these tests is described in reference 1. Prerotation was obtained by discharging compressed air through a nozzle and directing it tangentially against the tire tread. The air supply was automatically disconnected when the carriage began its horizontal movement.

The landing gear used in the tests was originally designed as the main gear of a small single-engine tail-wheel-type military training airplane having a gross weight of approximately 5,000 pounds. The gear is of conventional cantilever construction and incorporates a standard type of oleo-pneumatic shock absorber. The strut was inclined 15° (nose up) with respect to the vertical. The wheel was fitted with a 27-inch smooth-contour (type I) tire having a nonskid tread; the brake assembly was omitted. The original yoke, which was the half-fork type, was removed and replaced by a two-component dynamometer which provided the means of attaching the axle to the oleo shock strut. The dynamometer was designed to measure, by means of strain gages, loads up to 5,000 pounds in a direction normal to the strut and loads up to 10,000 pounds in a direction parallel to the strut. Accelerometers were used to measure the linear accelerations of the mass between the dynamometer and the ground, that is, the axle, wheel, and tire. From these acceleration measurements, the inertia reaction of the mass was obtained. The actual applied ground loads were obtained by adding these inertia forces to the dynamometer measurements. The accelerometers were of the unbonded strain-gage type. Those accelerometers measuring acceleration normal to the strut had a natural frequency of 850 cps and the accelerometers measuring accelerations parallel to the strut had a natural frequency of 150 cps. The general configuration and the location of the instruments are shown in figure 2.

The weight of the unsprung mass, which included everything below the movable part of the shock strut, was 274 pounds. The instruments used to measure the horizontal velocity of the carriage and vertical velocity of the model are described in reference 2.

The angular velocity of the wheel was determined by means of a segmented ring mounted on the wheel and brushes attached to the axle in such a manner that an electrical contact was made and broken 30 times during each revolution of the wheel. By counting the number of pulses on the oscillograph record within a short period of time just before contact, the angular velocity of the wheel at contact was determined.

The data from all the instruments were recorded on a multichannel recording oscillograph. The galvanometers were adjusted to 65 percent of critical damping and their natural frequencies were commensurate with those of the respective instruments to which they were connected. Timing lines at intervals of 0.01 second were produced on the records by means of an electronic timer built into the recorder.

The maximum errors in measurement are believed to be less than the following values:

Maximum drag load, lb	±285
Maximum vertical load, lb	±330
Horizontal velocity, fps	±1.5
Vertical velocity, fps	±0.1
Angular velocity at contact, percent	±1.5
Oscillograph timing, percent	±1

The tests were made with a dropping weight of 2,500 pounds and a horizontal velocity of approximately 85 fps. This velocity was very close to the maximum speed obtainable with the impact-basin carriage for the test weight. A series of landings with various amounts of prerotation was made at each of three vertical velocities. The vertical velocity at contact for each series was approximately 3.2, 7.5, and 9.5 fps. The amount of prerotation was varied from 0 to 115 percent; 100-percent prerotation refers to the wheel angular velocity for which the peripheral speed of the undeflected tire equals the ground speed.

RESULTS AND DISCUSSION

A tabulation of the experimental data obtained in the tests is presented in table I. The test results are also presented as plots showing the variations of the pertinent experimentally determined quantities.

Figure 3 shows the effect of prerotation on the maximum drag load obtained for various vertical velocities. The decrease in maximum drag load with an increase in prerotation is apparent. The plot also shows that higher vertical velocities yield higher maximum drag loads, as would be expected. Figure 4 shows the ratio of maximum drag load with prerotation to maximum drag load without prerotation plotted against prerotation. It is apparent that prerotation results in a larger percentage of drag-load reduction at the higher vertical velocities where the need for reduction is greatest.

Since, in these tests, 100-percent prerotation refers to the wheel angular velocity for which the peripheral speed of the undeflected tire equals the ground speed, the maximum drag load is not equal to zero at 100-percent prerotation. The reason is that the rolling radius of the wheel becomes smaller as the tire compresses under the vertical load and, consequently, the wheel must accelerate even though its peripheral speed was equal to the ground speed at contact. In order to bring about this angular acceleration, the drag load must be finite, as is indicated by the curves at 100-percent prerotation in figure 3. On the other hand, a slight amount of excess prerotation initially produces a small negative drag load, followed by a positive drag load which occurs for the same reason that a drag load occurs at 100-percent prerotation. The maximum values for both the negative and positive drag loads for 115-percent prerotation and vertical velocities of 7.5 and 9.5 fps appear in figure 3. Larger amounts of overspinning would result only in an increase in the negative drag load.

Although the drag load could be reduced to near zero with enough prerotation, using high percentages of prerotation at this forward speed seems to be impractical since an actual landing gear is subjected to loads other than spin-up drag loads and must be designed accordingly. For example, the design requirements for braked rolling (ref. 4) specify a vertical load factor of 1.2 and a drag reaction equal to 0.8 of the vertical. This requirement amounts to 2,400 pounds for the configuration tested. Figure 3 shows that approximately 60-percent prerotation is necessary to reduce the drag load to 2,400 pounds at the maximum vertical velocity used in these tests. Figure 4 shows that, with a vertical velocity of 9.5 fps, 60-percent prerotation results in a reduction in drag load of approximately 45 percent. This result indicates that, for the landing-gear configuration tested for forward speeds up to at least 85 fps, partial prerotation appears to be a practical method for obtaining appreciable reductions in the design spin-up drag loads.

Figure 5 shows the variation of the maximum drag load with initial skidding velocity for tests with prerotation and for tests without prerotation. The initial skidding velocity is defined as the difference between the peripheral velocity of the tire and the forward speed at the time of ground contact. For tests made without prerotation the ground speed and the skidding velocity at contact are synonymous. All the prerotation tests were at a forward speed of approximately 85 fps. The data for tests at other forward speeds without prerotation were obtained from the investigation of reference 1. Since the maximum drag-load values for tests with prerotation fall on the same curve as those without prerotation, insofar as the maximum drag load is concerned the effect of prerotation is seen to be the same as the effect of reducing the forward speed.

Figure 6 shows a comparison of the time histories of the drag load for tests with prerotation and without prerotation at several selected initial skidding velocities. In all these tests the vertical velocity was 9.5 fps. For tests with approximately the same initial skidding velocity, the time histories are similar; however, for the tests with prerotation a slightly longer time is required to reach the maximum drag load. It might be mentioned that a similar comparison using tests with a vertical velocity of 7.5 fps produced similar results with better agreement in the time to reach maximum drag load.

The foregoing results apply only to the forward-speed test range of the impact-basin equipment which is limited to approximately 85 fps. In this range the maximum drag load increases with the initial skidding velocity at contact as shown in figure 5. However, at higher skidding velocities beyond the range of these tests, data obtained previously show that the maximum drag load reaches a peak and then decreases with further increases in initial skidding velocity. This result is illustrated in figure 7 which shows results obtained from tests in which forward speeds greater than 85 fps were simulated by making forward-speed tests combined with reverse rotation of the wheel (ref. 1). Although the values obtained may not be exactly equal to those for corresponding pure forward-speed tests, the general shape of the curve is believed to be realistic and indicates some important conclusions regarding the effects of prerotation on wheel spin-up drag loads at forward speeds exceeding the testing range of the impact-basin equipment.

Because the drag load decreases with increasing velocity beyond 120 fps, prerotation must be used judiciously if any practical gain is to be obtained. In this region an insufficient amount of prerotation may actually increase the drag load. For example, at a forward speed of 200 fps, figure 7 indicates a drag load of about 2,700 pounds. The skidding velocity would have to be reduced to about 50 fps or less (75-percent prerotation or more) in order to reduce the drag load below 2,700 pounds. Any amount of prerotation less than 75 percent would, at this forward speed, actually cause the drag load to be greater than it would be with no prerotation. Furthermore, since the wheel spin-up drag loads at the very high forward speeds may become less than the drag loads caused by other sources, such as braking (as previously indicated, 2,400 pounds for this configuration), there is no point in trying to reduce the drag load still further by use of prerotation at these very high forward speeds.

The time required to reach maximum drag load has a bearing on the dynamic stresses of a landing gear and other aircraft components as well, and its variation with prerotation for three vertical velocities is therefore shown in figure 8. This figure shows that considerably less time is required to bring the wheel up to speed as the amount of prerotation is increased. Less time was also required to spin up the wheel during tests made at the high vertical velocity than during the tests made at the low vertical velocity. This result is to be expected since higher drag loads were obtained in the tests with higher vertical velocity (fig. 3).

The effect of prerotation on the maximum vertical loads for a forward speed of approximately 85 fps is shown in figure 9 for various vertical velocities. This figure shows that the maximum vertical load decreased with an increase in prerotation, the maximum reduction occurring at prerotation values in the region of 80 to 85 percent. Figure 10 shows the ratio of the maximum vertical load with prerotation to the maximum vertical load without prerotation plotted against the prerotation. In this forward-speed condition the percentage of vertical-load reduction throughout most of the range of prerotation is seen to be essentially independent of the vertical velocity. The maximum reduction in vertical load is approximately 20 percent at the higher vertical velocities.

The reduction in vertical load is a result of the decrease in drag load brought about by prerotation. First, the reduced drag load results in a reduced component of force normal to the shock strut which reduces the friction within the telescoping portions of the strut. Second, since the strut was tested at 15° inclination, the component of the drag force parallel to the longitudinal axis of the shock strut is reduced; thus, the closing velocity of the strut is reduced and the axial force is also reduced. These components of load are the loads applied to the shock strut and they differ from the applied ground loads described previously by an amount equal to inertia forces which result from the accelerations of the mass between the shock strut and the ground.

Although this paper is mainly concerned with the effect of prerotation on the applied ground loads, several other aspects of prerotation should be mentioned, such as the effects of prerotation on the length of the landing distance and on tire wear.

The additional energy that would have to be dissipated by the brakes during a landing with 100-percent prerotation is the amount required to spin up the wheels in a landing without prerotation. This amount is very small compared with the total energy of the airplane and the additional landing distance required would therefore also be very small.

It would seem that prerotation should greatly decrease tire wear; however, the tests at the impact basin, where the only source of wear is that encountered in spinning up the wheel in landing, indicated that prerotation should result in no significant gain in tire life. About 450 simulated landings have been made without prerotation and yet the tire tread was not visibly worn. The tires on an airplane having a landing gear of the same type tested in the impact basin were worn out, however, in a substantially lower number of actual landings. It would appear, therefore, that wheel spin-up is not the chief source of tire wear for the configuration tested compared with other sources such as braking and turning and no significant gain in tire life should be expected from the use of prerotation.

CONCLUSIONS

The effect of prerotation on the wheel spin-up drag loads on a small landing gear was investigated by means of forward-speed tests in the Langley impact basin. The tests were made with a dropping weight of 2,500 pounds and a forward speed of approximately 85 fps at a strut angle of 15°. The results of these tests and previously obtained data indicate the following conclusions:

1. For horizontal velocities up to at least 85 fps, prerotation, even partial prerotation, appears to be a practical method for obtaining appreciable reductions in the spin-up drag loads.

2. A given amount of prerotation yields somewhat larger percentages of drag-load reduction as the vertical velocity increases.

3. Insofar as the maximum drag load is concerned, the effect of prerotation is the same as the effect of reducing the forward speed to a comparable value of skidding velocity at contact.

4. A consideration of the variation of drag load with forward speed, as shown in a previous investigation, indicates that there is a value of forward speed (in this instance about 120 fps) beyond which the maximum drag load decreases with increasing forward speed. For this higher forward-speed range, therefore, large percentages of prerotation must

be used to secure any drag-load reduction; in fact, an insufficient amount of prerotation may actually increase the drag load.

5. Because of the reduced drag loads at very high forward speeds, prerotation may not be useful since these drag loads may be less than the design loads from other sources, such as braking.

6. In the forward-speed range where prerotation was tested, reductions in drag load resulting from prerotation were accompanied by reductions in vertical load.

7. This investigation and previous tests involved over 450 simulated landings without prerotation during which very little tire wear occurred. It thus appears that for the configuration tested the wheel spin-up process is a relatively small factor in tire wear and therefore prerotation should not be expected to materially increase tire life.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 20, 1954.

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1. Milwitzky, Benjamin, Lindquist, Dean C., and Potter, Dexter M.: An Experimental Investigation of Wheel Spin-Up Drag Loads. NACA TN 3246, 1954. (Supersedes NACA RM L53E06b.)

2. Batterson, Sidney A.: The NACA Impact Basin and Water Landing Tests of a Float Model at Various Velocities and Weights. NACA Rep. 795, 1944. (Supersedes NACA WR L-163.)

3. Milwitzky, Benjamin, and Lindquist, Dean C.: Evaluation of the Reduced-Mass Method of Representing Wing-Lift Effects in Free-Fall Drop Tests of Landing Gears. NACA TN 2400, 1951.

4. Anon.: Ground Loads. ANC-2, Munitions Board Aircraft Committee, Dept. of Defense, Oct. 1952.

TABLE I.- INITIAL IMPACT CONDITIONS AND MAXIMUM DRAG LOADS AND VERTICAL LOADS

Test number	Horizontal velocity, fps	Vertical velocity, fps	Prerotation (peripheral speed), fps	Maximum drag load, lb	Maximum vertical load, lb	Time to reach maximum drag load, sec
1	84.7	9.41	0	4,270	9,390	0.038
2	84.2	9.40	0	4,390	8,930	.040
3	84.1	9.50	0	4,500	9,340	.035
4	84.1	9.59	0	4,350	8,850	.036
5	84.2	9.38	19.7	3,890	8,240	.033
6	84.5	9.48	26.3	3,530	8,660	.026
7	85.0	9.51	33.7	3,170	8,480	.029
8	85.0	9.62	40.8	3,060	8,270	.021
9	85.3	9.40	47.7	2,580	7,800	.024
10	84.4	9.66	54.4	2,280	7,870	.019
11	85.0	9.44	61.6	1,920	7,540	.018
12	85.4	9.41	65.2	1,610	7,500	.017
13	84.6	9.59	72.2	1,180	7,520	.013
14	84.7	9.29	75.5	990	7,610	.012
15	85.5	9.41	80.2	670	7,770	.008
16	85.3	9.37	81.6	520	7,480	.007
17	84.7	9.44	82.0	420	7,470	.006
18	85.6	9.48	96.7	-650	7,900	.006
19	84.7	7.43	0	3,520	6,800	.044
20	85.0	7.59	0	3,750	6,910	.042
21	84.4	7.43	19.5	3,110	6,140	.036
22	83.4	7.58	29.4	2,940	6,520	.031
23	84.2	7.43	39.4	2,640	5,900	.029
24	84.4	7.39	40.1	2,550	5,860	.028
25	84.7	7.50	50.3	2,140	5,980	.021
26	85.4	7.54	61.0	1,520	-----	.018
27	84.8	7.47	61.6	1,540	5,510	.019
28	84.1	7.43	68.4	1,220	5,550	.016
29	84.7	7.54	72.8	1,010	5,440	.013
30	84.2	7.39	77.4	630	5,550	.008
31	83.6	7.43	77.6	630	5,680	.008
32	85.0	7.54	83.0	390	5,740	.007
33	84.9	7.50	97.6	-720	5,970	.008
34	83.8	3.29	0	1,880	3,090	.059
35	84.5	3.20	12.4	1,830	2,720	.053
36	83.7	3.13	24.0	1,620	2,910	.045
37	84.7	3.18	35.5	1,640	2,910	.039
38	83.5	3.28	48.3	1,400	2,490	.034
39	83.6	3.33	60.5	1,080	2,510	.027
40	84.3	3.29	72.0	650	2,240	.018
41	84.0	3.26	81.9	320	2,280	.007

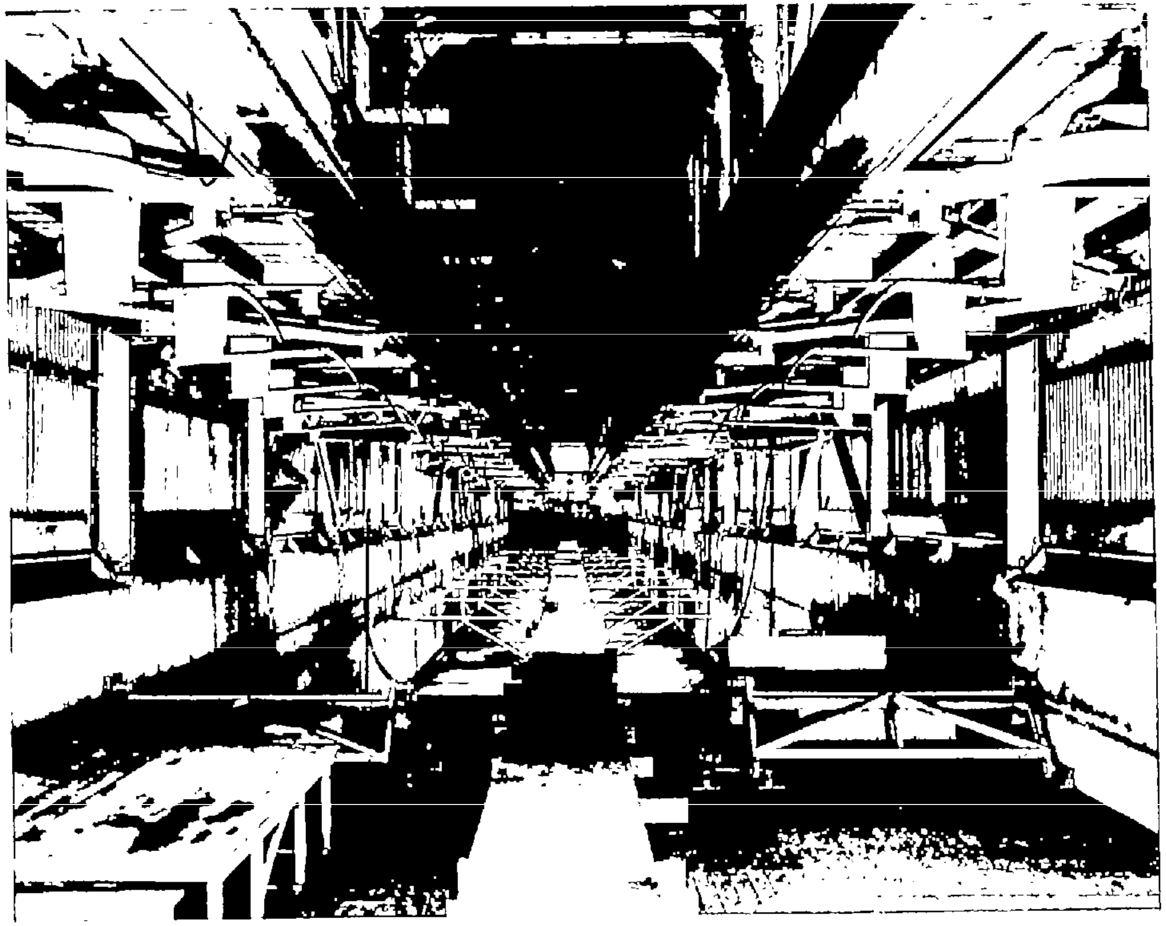

Figure 1.- Concrete runway in Langley impact basin. L-62850

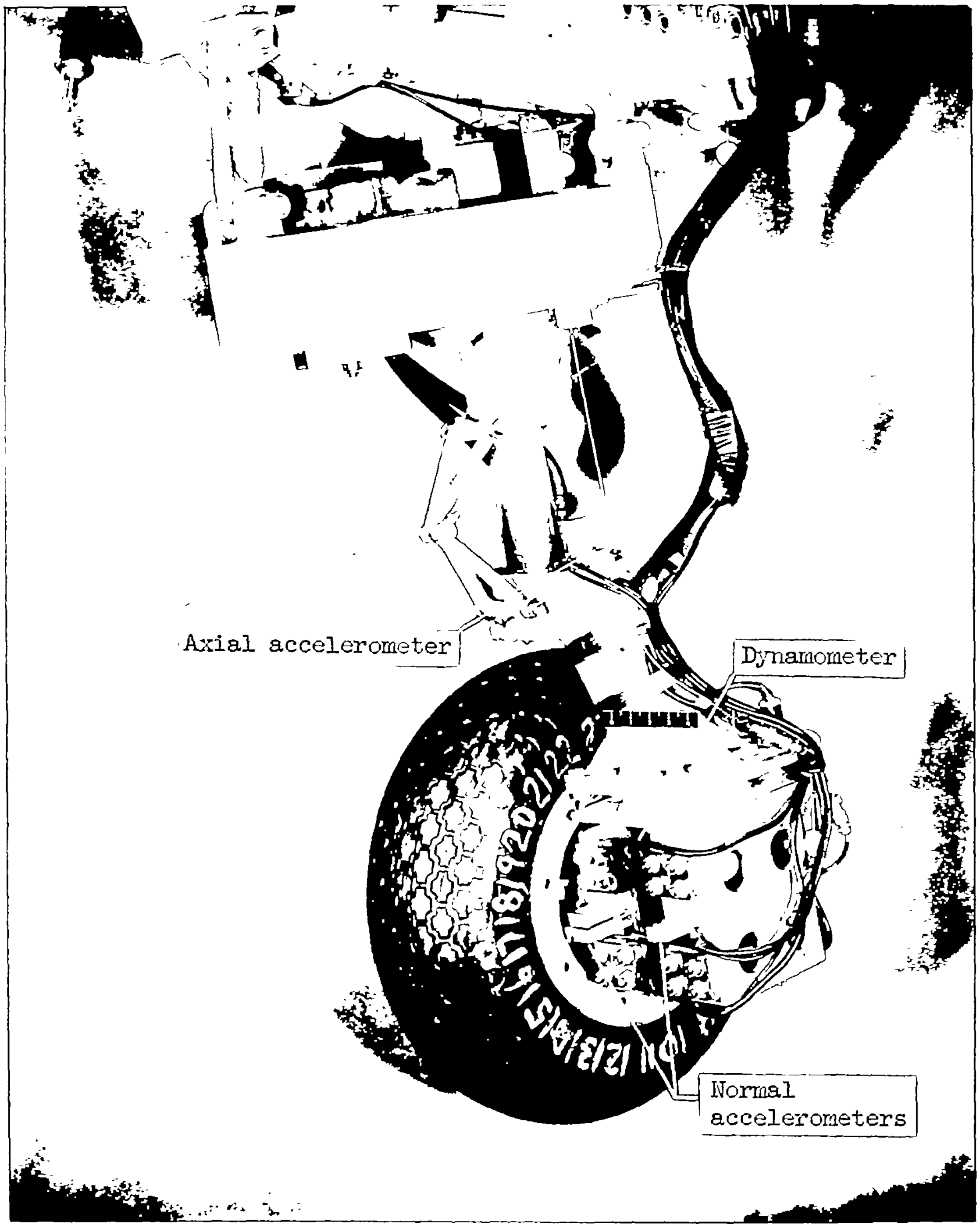

Figure 2.- Landing gear and instrumentation used in prerotation tests.

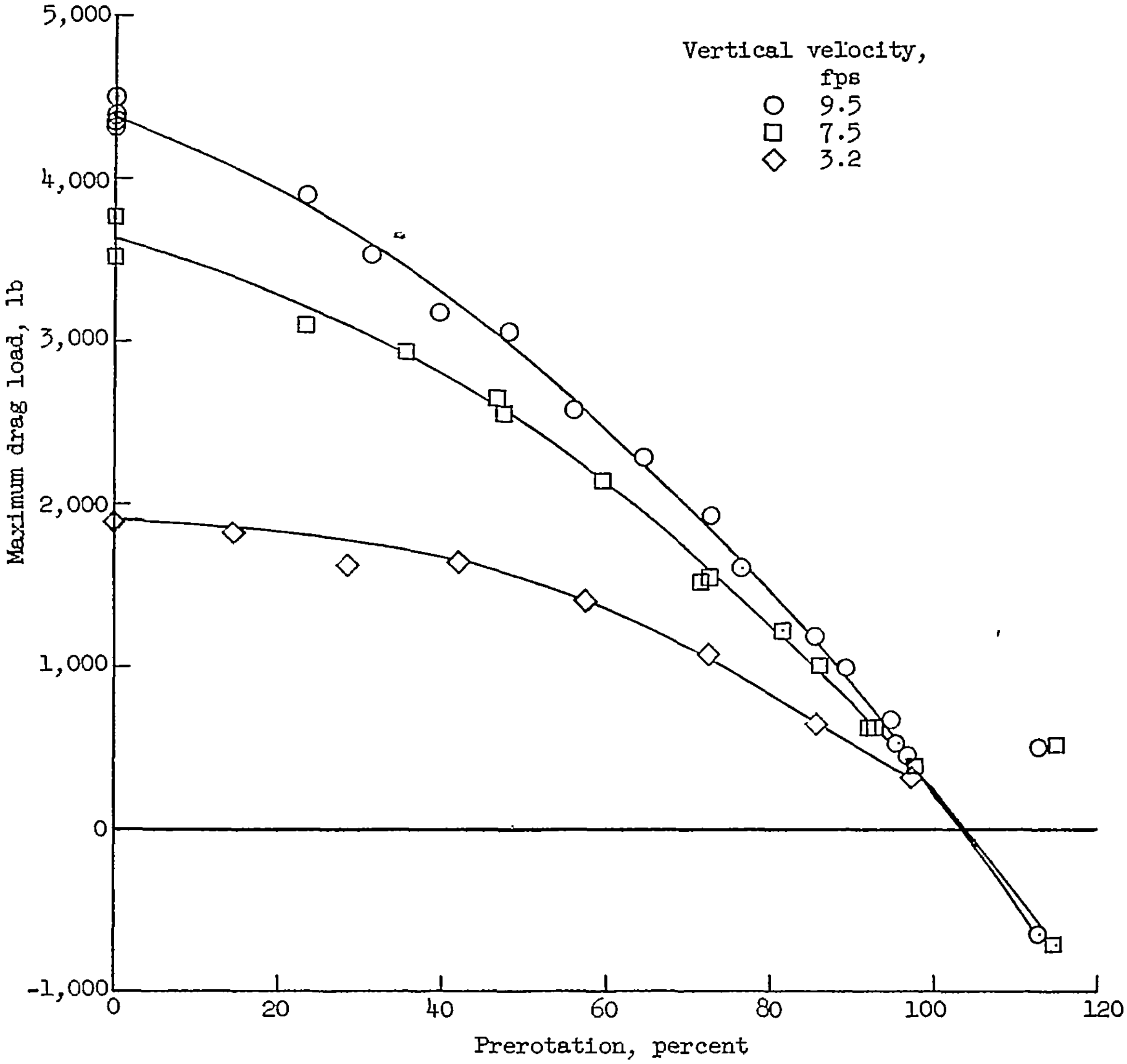

Figure 3.- Effect of prerotation on maximum drag load. Forward speed, 85 fps.

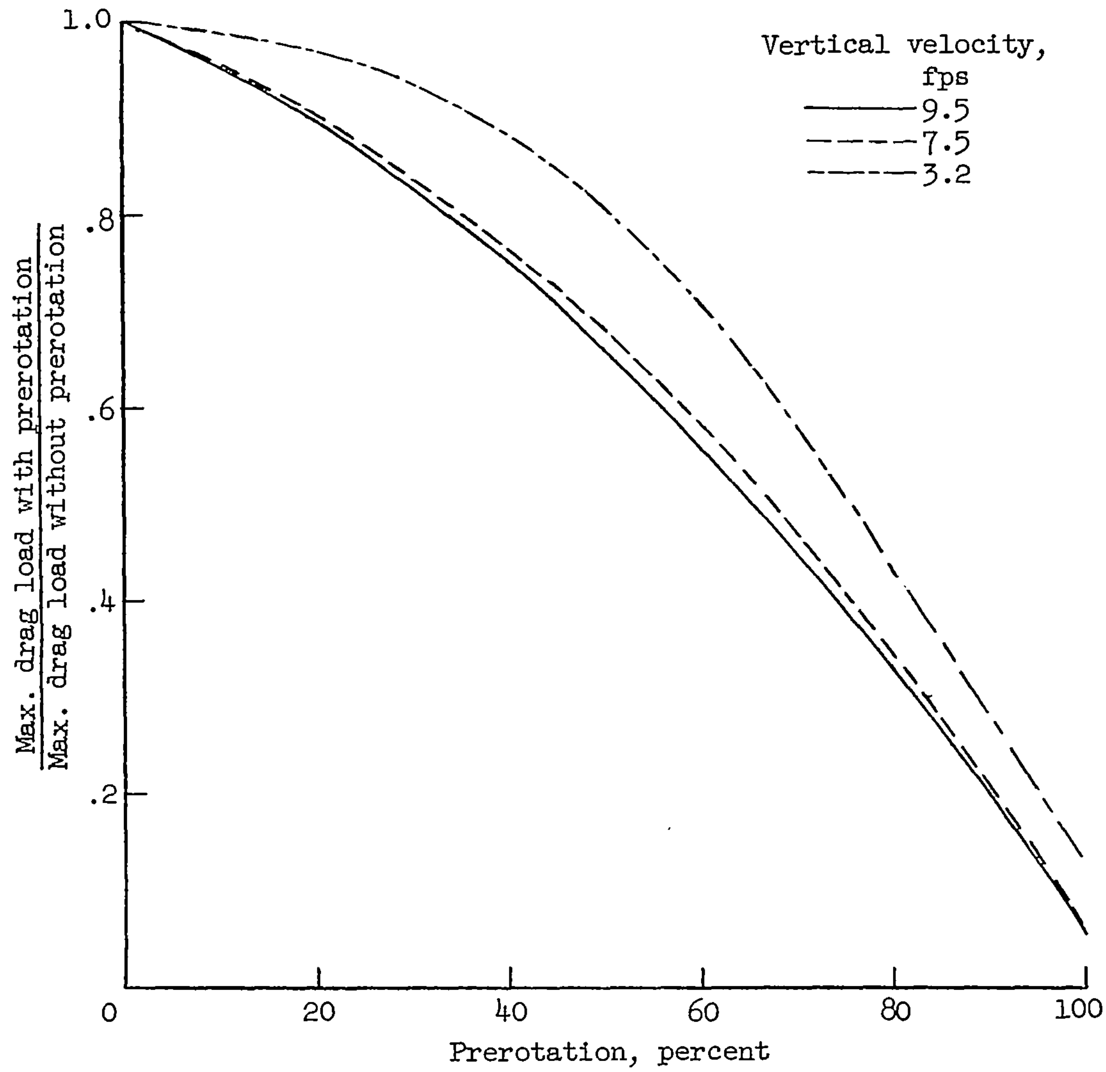

Figure 4.- Ratio of maximum drag load with prerotation to maximum drag load without prerotation as a function of prerotation. Forward speed, 85 fps.

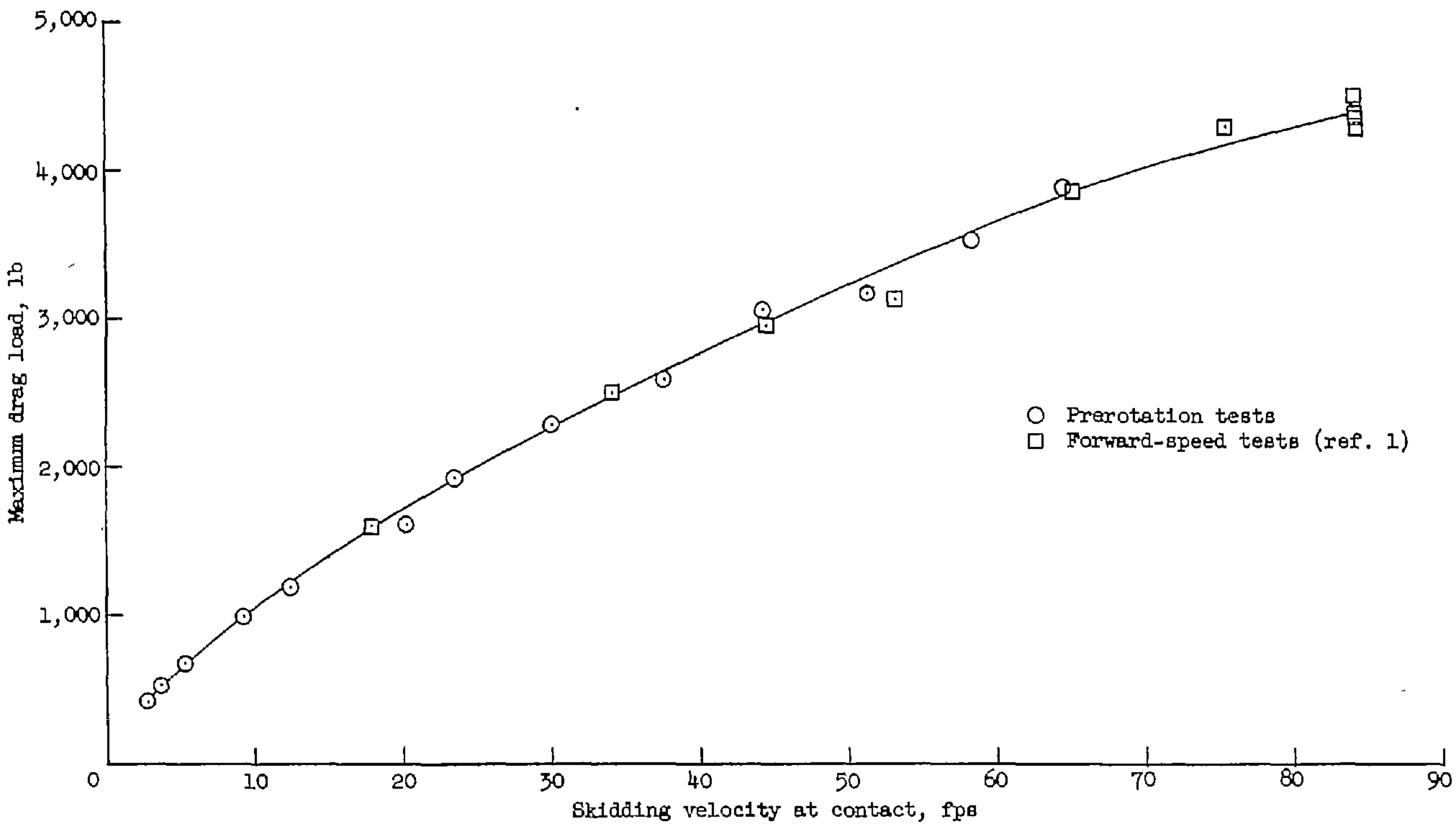

Figure 5.- Comparison of maximum drag load in prerotation and forward-speed tests. Vertical velocity, 9.5 fps; forward speed in prerotation tests, 85 fps.

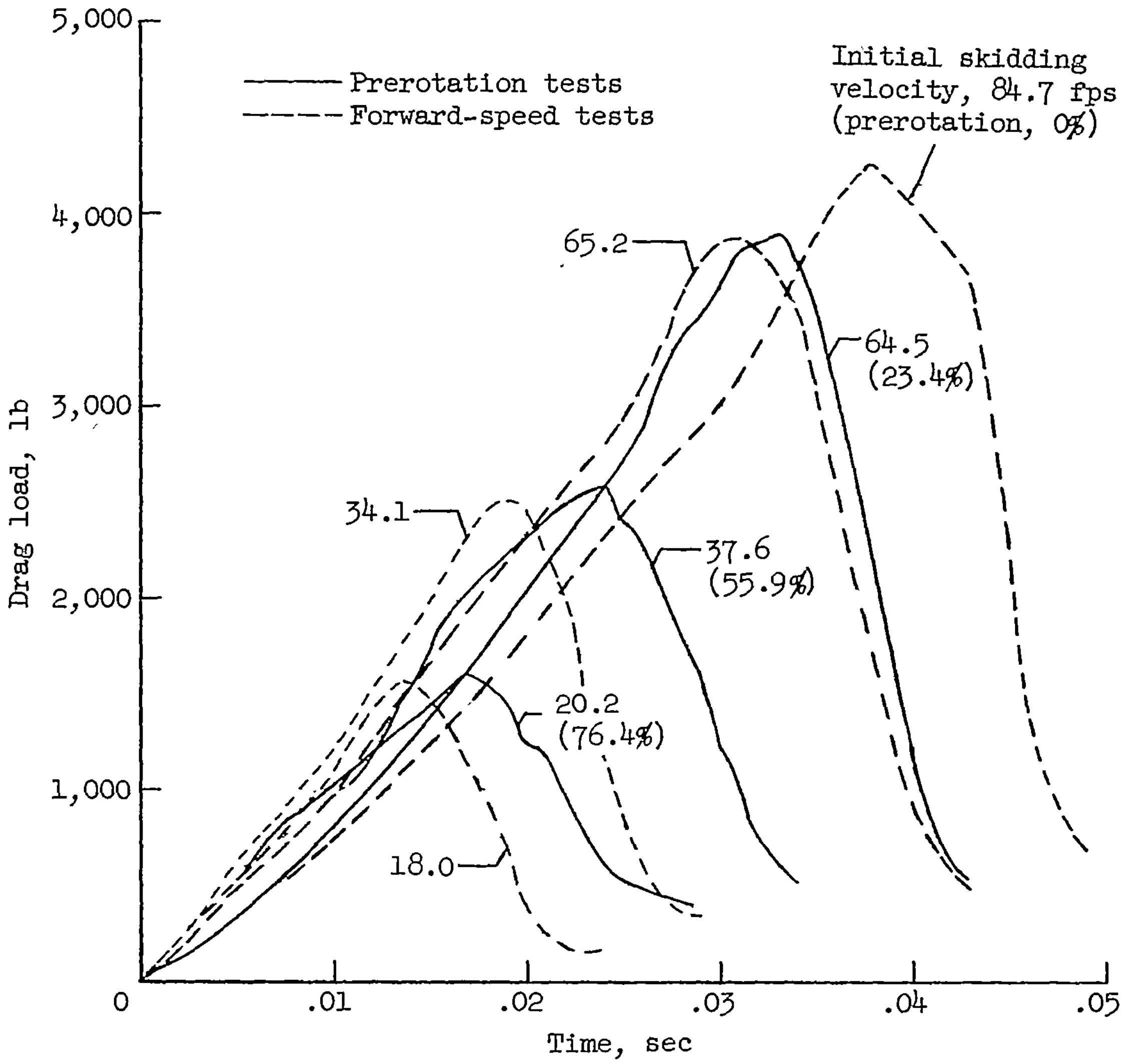

Figure 6.- Comparison of drag-load time histories in prerotation and forward-speed tests for several initial skidding velocities. Vertical velocity, 9.5 fps; forward speed in prerotation tests, 85 fps.

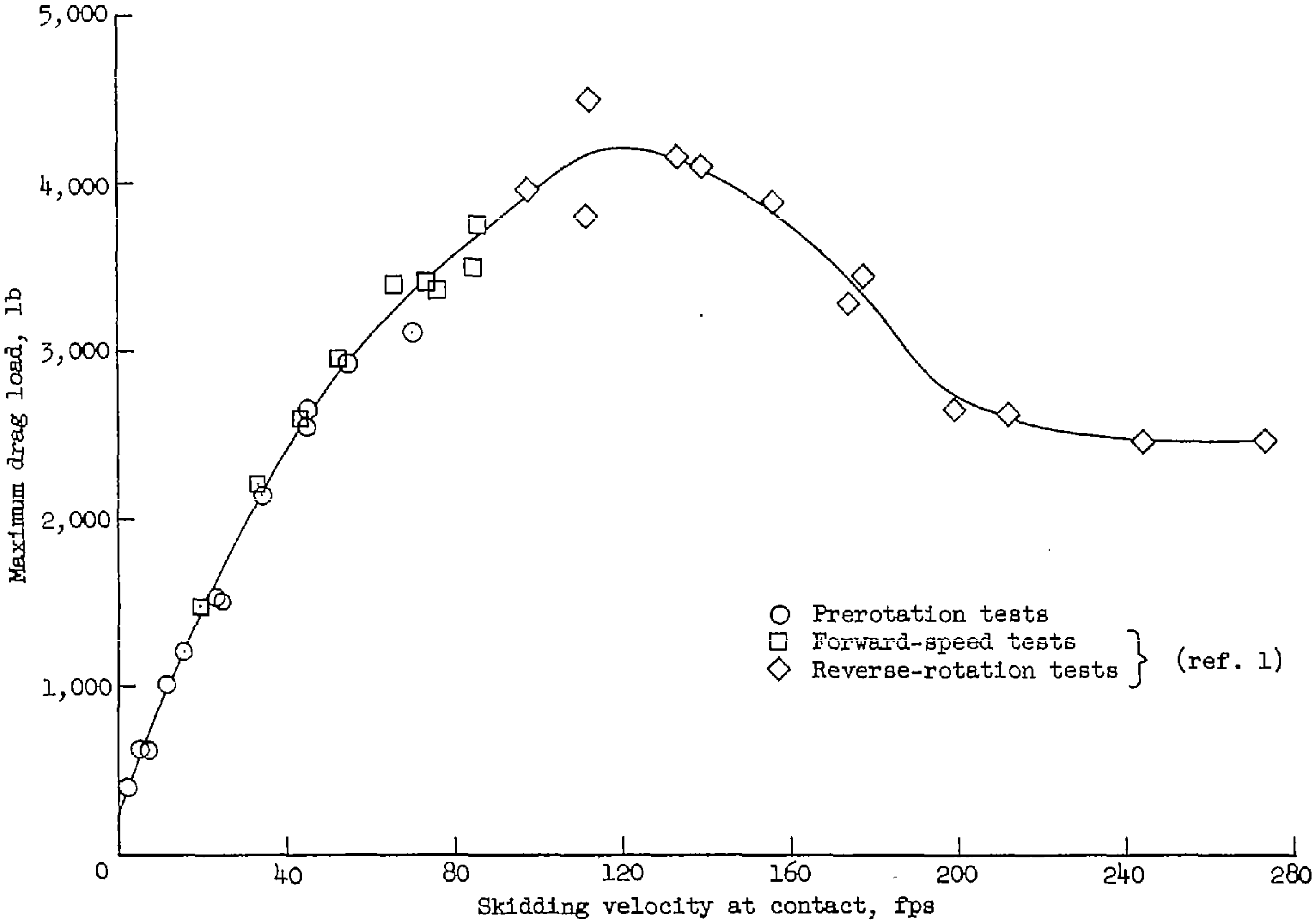

Figure 7.- Variation of maximum drag load in prerotation, forward-speed, and reverse-rotation tests. Forward speed in prerotation and reverse-rotation tests, 85 fps; vertical velocity, 7.5 fps.

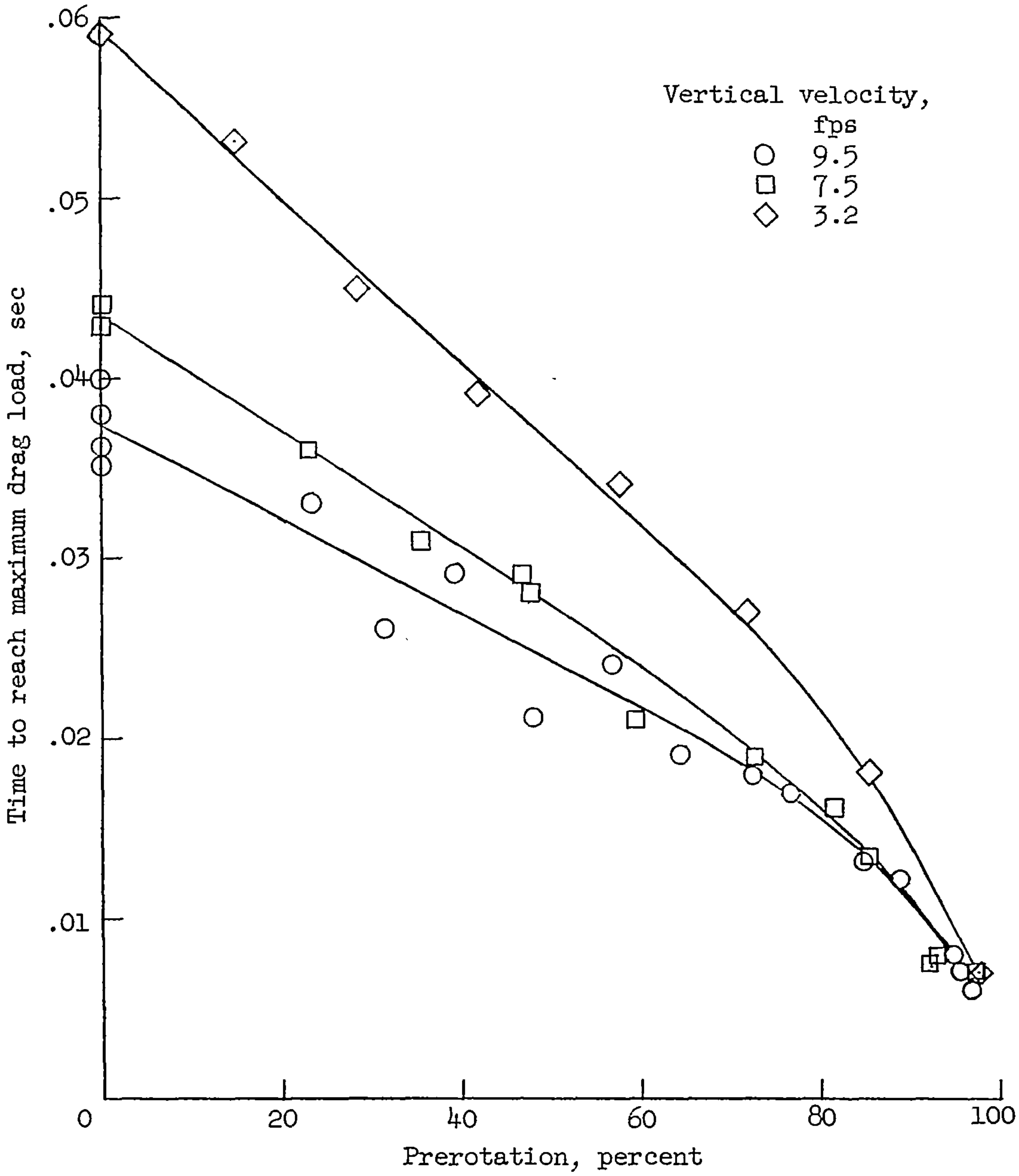

Figure 8.- Effect of prerotation on time to reach maximum drag load. Forward speed, 85 fps.

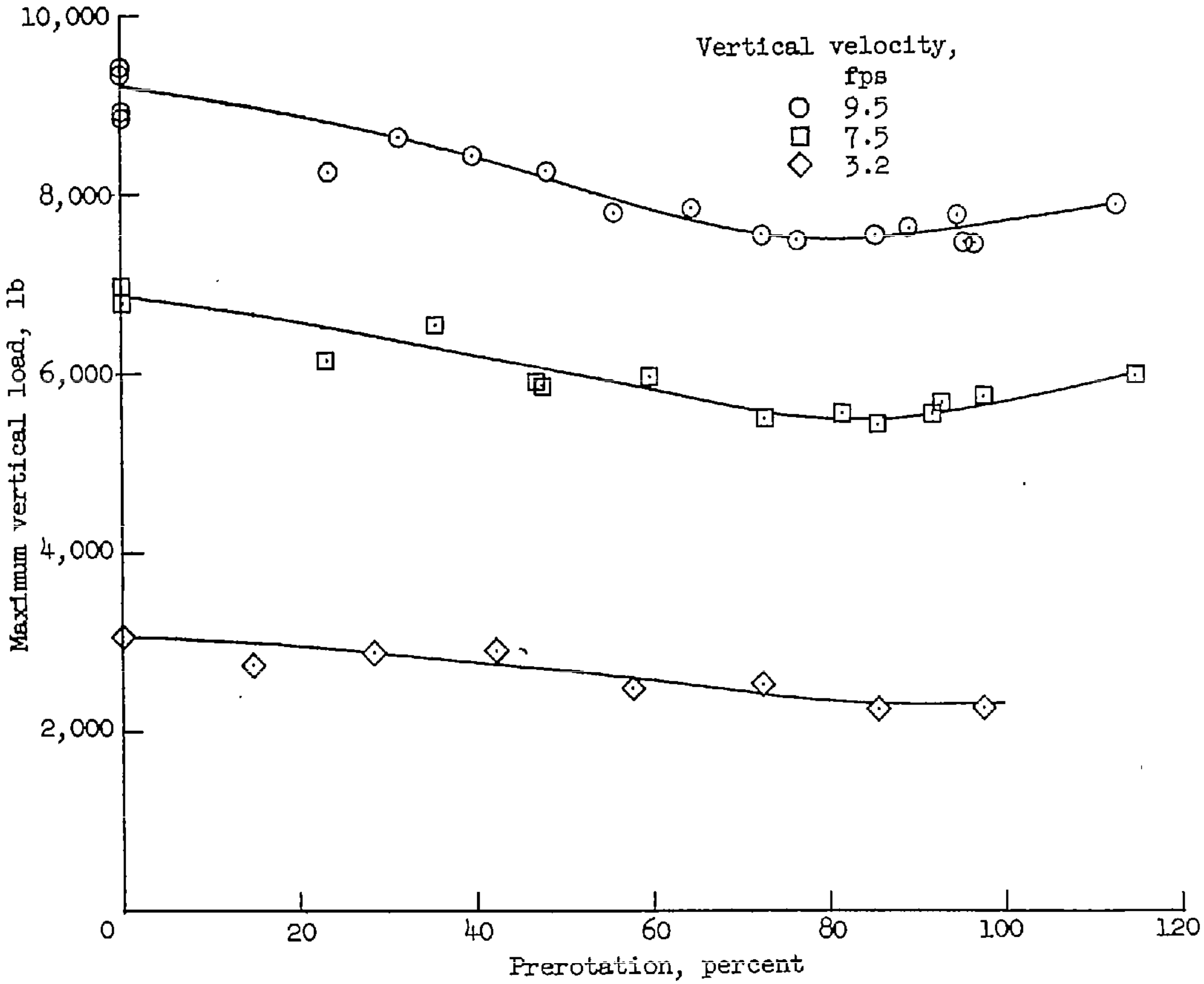

Figure 9.- Effect of prerotation on maximum vertical load. Forward speed, 85 fps.

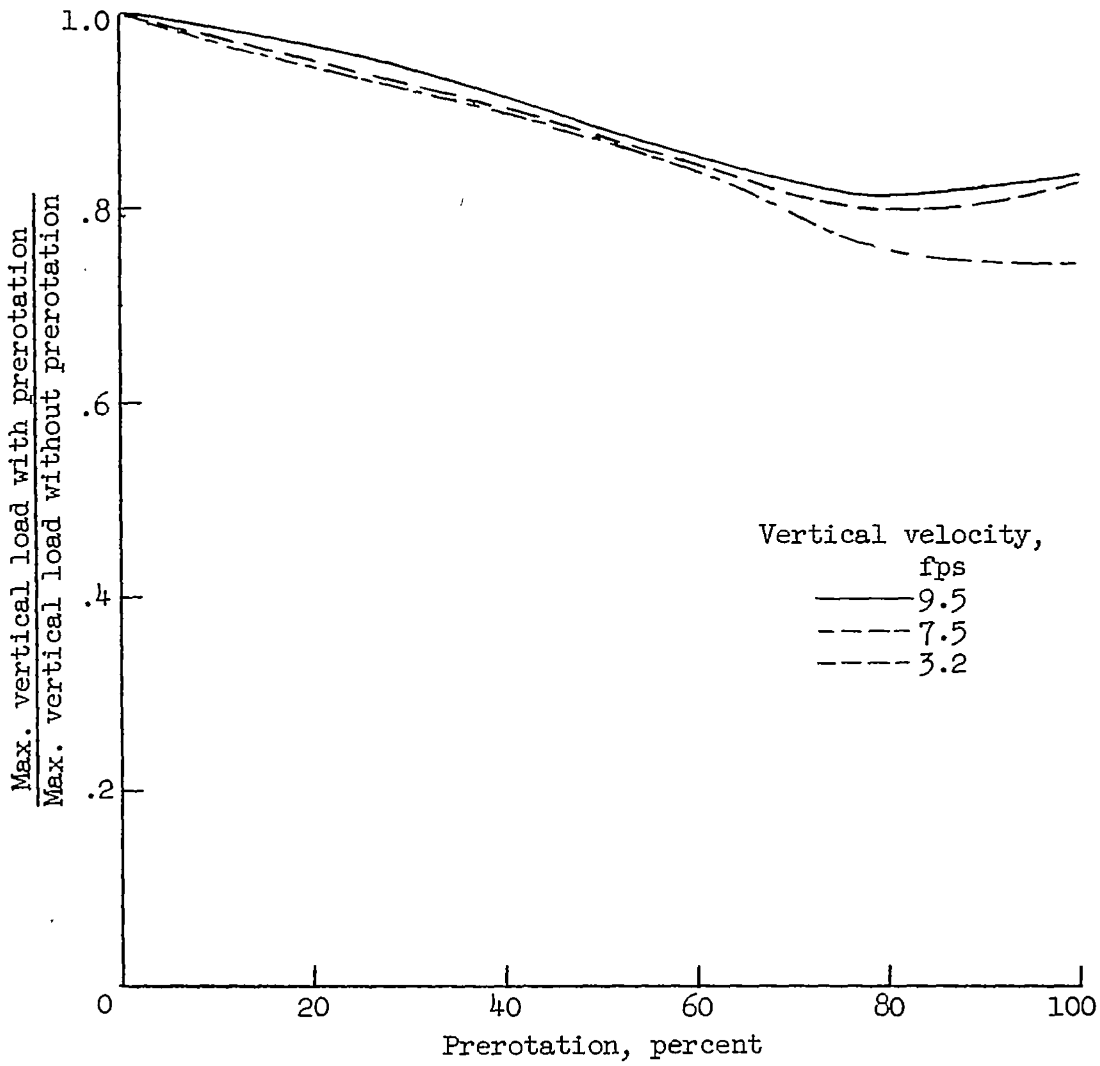

Figure 10.- Ratio of maximum vertical load with prerotation to maximum vertical load without prerotation as a function of prerotation. Forward speed, 85 fps.

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